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Operating in a GPS Denied Environment in the PACOM Maritime Domain

by

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A paper submitted to the Faculty of the Naval War College in partial satisfaction of the requirements of the Department of Joint Military Operations.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

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Abstract

On the open ocean, naval ships rely on navigation signals provided by the Global Positioning System (GPS) almost exclusively. The GPS satellite constellation, however, is increasingly vulnerable to disruptions and outages. This paper argues that, although the risk is low, the possibility exists that future operating conditions will force the U.S. Pacific Command (PACOM) combatant commander to operate in a GPS denied environment, and he should make adjustments in his maritime planning to compensate for this critical vulnerability. Specifically, analysis using operational factors examines the problem and determines how GPS unavailability at sea affects the PACOM combatant commander's ability to accomplish his military objectives. This paper then provides several recommendations to mitigate the risk of operating in a GPS denied environment within the PACOM maritime domain. If the PACOM commander incorporates these recommendations into his operational planning, he will reduce potential friction within friendly forces and obtain conditions most favorable to successfully meeting his military objectives while operating in a GPS denied environment.

INTRODUCTION

The United States military increasingly depends on satellite navigation to accurately move and maneuver forces around the globe. The U.S. Navy is no exception. On the open ocean, naval ships rely on navigation signals provided by the Global Positioning System (GPS) almost exclusively. The GPS satellite constellation, however, is vulnerable to disruptions and outages. The natural question that follows, then, is how would the U.S. Navy navigate the seas in a GPS denied environment?

The dependency and vulnerability of GPS is a complex, national issue, affecting multiple segments of American government and society, including the aviation, banking, agricultural, and military communities. This paper significantly narrows the scope of this problem and focuses only on how it relates to U.S. Navy surface navigation in the U.S. Pacific Command (PACOM) area of responsibility (AOR). Although a related issue, weapons carried on U.S. naval ships that use GPS for precision guidance will not be addressed. This does not negate the importance of this issue; however, targeting with GPS is a distinct and separate issue and, hence, is considered outside the scope of this analysis.

This paper argues that, although the risk is low, the possibility exists that future operating conditions will force the PACOM combatant commander to operate in a GPS denied environment, and he should make adjustments in his maritime planning to compensate for this critical vulnerability. Specifically, analysis using operational factors will examine the problem and determine how GPS unavailability at sea affects the PACOM combatant commander's ability to accomplish his military objectives. This paper then provides several recommendations to mitigate the risk of operating in a GPS denied environment within the PACOM maritime domain. If the PACOM commander incorporates

these recommendations into his operational planning, he will reduce potential friction within friendly forces and obtain conditions most favorable to successfully meeting his military objectives while conducting operations in a GPS denied environment.

BACKGROUND – THE PROBLEM

Before proceeding, it is necessary to prove that operating in a GPS denied environment is a potential problem for U.S. Navy surface ships. There are three requirements to substantiate this as an issue for the PACOM commander. First, it must be established that GPS is vulnerable to outages that could prevent transmission of navigation signals to surface ships in the PACOM AOR. There are several circumstances, both intentional and unintentional, that could prevent accurate GPS signals from reaching naval ships. Intentional kinetic or non-kinetic attacks against multiple GPS satellites or the ground control stations could render the system unreliable or completely unavailable either temporarily or permanently. Although upgrades in the GPS constellation provide security measures to protect against non-kinetic attacks,¹ China, as an example, is widely known to be pursuing capabilities in the cyberspace domain. Coupled with their anti-satellite program, which they tested successfully in 2007 by destroying one of their own spacecraft, China is implementing an anti-access area denial (A2/AD) strategy that includes satellite capabilities.²

Hostile attack, however, is not the only vulnerability of GPS; GPS is also vulnerable to non-hostile, unintentional actions and occurrences. This includes human error and space environment phenomenon. For example, an improperly tested software upload at the GPS ground control station in January 2010 caused up to 10,000 military receivers to lose their navigation capability for a period of days.³ Human error also resulted in the upload of erroneous navigation data in March 1993, March 2000, and June 2002.⁴ Although these

instances did not produce catastrophic results, it is feasible that similar circumstances could propagate flawed data throughout the GPS constellation, making all GPS signals inaccurate and therefore receivers onboard ships useless.⁵

The space environment and solar events pose other vulnerabilities. Spacecraft are designed to withstand the harsh environment of space, but solar events have the potential to severely damage satellites' electronic equipment. Individual solar events are difficult to predict, but tend to occur with more frequency and more strength at the peak of the 22-year solar cycle. The peak, also called solar maximum, is approaching in the next few years, and could bring significant solar storms.⁶ In February 2011, the largest solar flare in four years occurred, affecting GPS signals only temporarily.⁷ Yet this solar flare was small compared to the largest one on record, which occurred in 1859 with great similarities to the current solar cycle.⁸ This so-called Carrington Event occurred before the age of satellites; an event of this magnitude now could have drastic effects on high technology infrastructure, particularly satellites.⁹ The U.S. Air Force operates the GPS constellation, and it is telling that the U.S. Air Force top officer, Chief of Staff General Norton Schwartz, publicly stated in January 2010 that the military should "reduce its dependence on GPS aid."¹⁰

Even if the risk is assessed as low, given the above examples, GPS is vulnerable to disruptions and outages, whether by an intentional attack or by non-hostile means, that could prevent accurate navigation signals from reaching naval ships in PACOM. With the first criteria satisfied, the second requirement to validate GPS unavailability as a problem for the PACOM commander is to show that U.S. Navy ships rely heavily on GPS signals for navigation and have no equivalent backup system in place. Faculty at the U.S. Navy's Surface Warfare Officer School in Newport, Rhode Island, confirm this as the case.¹¹ All

U.S. naval ships are dependent on GPS-supported navigation systems for their primary means of navigation, particularly in the open ocean.¹² At their best, military navigation systems using GPS and various augmentation methods are accurate to centimeters¹³; at worst, they provide accuracy within 12.6 meters at a 95% confidence level.¹⁴ Naval ships are also equipped with inertial navigation systems, but their accuracy is not nearly as precise as GPS and degrades over time.¹⁵ Accuracy varies relative to the quality of system components, but one military inertial navigation system, the AN/WSN-7 Ring Laser Gyro Navigator, advertises accuracy up to one nautical mile eight hours after the loss of a GPS signal.¹⁶ This error continues to accumulate, which means the navigation data it provides could be six nautical miles off after two days without a GPS signal. This is significant when compared to primary GPS-enabled navigation systems onboard U.S. naval assets.

Celestial navigation is another potential backup method, but few naval officers possess an adequate understanding of this age-old skill, with the U.S. Naval Academy teaching only a limited version of the course since 1998.¹⁷ Celestial navigation is no longer taught in any form at the Surface Warfare Officer School; however, some current commanding officers have mandated their surface warfare officers learn the skill as a personal preference and for the added assurance of an additional navigational backup.¹⁸ Only accurate to a three-mile radius, celestial navigation is clearly not as accurate as GPS,¹⁹ and some ships have even stopped carrying the charts needed to use it as a worst-case backup.²⁰ Thus, although naval ships have at least one backup navigation method, the backup methods are not nearly as capable as the primary GPS-enabled systems, and in the case of celestial navigation, may or may not be available to the crew.

Lastly, to qualify as an operational problem, the fact that U.S. naval ships are reliant on GPS for navigation and that GPS is vulnerable to outages must matter to the PACOM combatant commander. It must affect his ability to accomplish his mission on an operational level. In PACOM's case, the stated mission is as follows:

U.S. Pacific Command (USPACOM), together with other U.S. Government agencies, protects and defends the United States, its territories, Allies, and interests; alongside Allies and partners, promotes regional security and deters aggression; and, if deterrence fails, is prepared to respond to the full spectrum of military contingencies to restore Asia-Pacific stability and security.²¹

This is a general mission statement, as one would expect at the combatant command level in peacetime. Moving down the chain of command, mission statements gradually become more specific in terms of how subordinate commanders plan to support the combatant commander; service component commanders narrow the focus to their particular domain and how they can uniquely contribute to the mission. The U.S. Navy's service component to PACOM is U.S. Pacific Fleet (PACFLT), and in its role, PACFLT's mission is to support the objectives of PACOM. PACFLT's mission is specifically stated below:

U.S. Pacific Fleet protects and defends the collective maritime interests of the United States and its allies and partners in the Asia-Pacific region. In support of U.S. Pacific Command and with allies and partners, U.S. Pacific Fleet enhances stability, promotes maritime security and freedom of the seas, deters aggression and when necessary, fights to win.²²

This mission statement is still quite general, but more specific than PACOM in that it focuses on maritime interests and promoting maritime security and freedom of the seas. In terms of operational functions, a loss of GPS would directly affect PACFLT's ability to move and maneuver while protecting and defending maritime interests and fighting any necessary battles. Movement and maneuver, with appropriate backup systems, at a minimum, would be less accurate and slower and involve additional friction. At worst,

forces would be overcome by friction and unable to navigate to the appropriate locations in sufficient time to affect the commander's objectives. In peacetime, a loss of GPS might not be significant, but during a crisis situation or war, when timing and accuracy matter, this could be disastrous. Thus, this is a potential problem the PACOM combatant commander should be aware of and consider during his planning.

DISCUSSION / ANALYSIS

Developing solutions to overcome this problem requires methodical analysis in order to fully explore all possible courses of action. All military analysis should begin with the objective in mind, and the above mission statements of PACOM and PACFLT meet this purpose. In terms of how PACFLT seeks to achieve its objectives, and thus PACOM's objectives, one looks to *A Cooperative Strategy for 21st Century Seapower* for specific guidance. To provide maritime power, the U.S. Navy, and hence PACFLT, relies on six core capabilities: Forward Presence, Deterrence, Sea Control, Power Projection, Maritime Security, and Humanitarian Assistance and Disaster Response.²³ These capabilities will be used to examine how a lack of GPS navigation capability onboard PACFLT surface ships impacts the operational mission, or objectives, of PACOM, with respect to the operational factors of time, space, and force.

Time is the only operational factor that a military force cannot regain once lost, and thus is the most important of the three operational factors.²⁴ A loss of GPS navigation ability onboard U.S. surface ships can negatively affect time, by increasing the amount of time required to accurately navigate to a desired location. This affects all six core capabilities, although in varying degrees based on the urgency of the situation. As the largest geographic combatant command, PACOM covers 100 million square miles, and as a result, the

operational factor of space plays an important role as well.²⁵ The larger the space, the greater the need is for accuracy in navigation; without GPS, the large amount of space is more difficult to manage. Likewise, the third operational factor of force is also adversely affected by a GPS denied environment. If an adversary knows that a military force is without its primary navigation tool, as it would in the event of a complete GPS outage, it sees that force as weakened. With this brief synopsis of the operational factors, it is now beneficial to examine the six core capabilities of the U.S. Navy individually.

A GPS denied environment could affect the first of the six core capabilities, forward presence, considerably. PACOM maritime forces are forward deployed on a day-to-day basis and thus, under normal circumstances, do not have to navigate expansive distances. In a crisis situation, however, forces may need to alter their locations within the theater, or additional forces may need to forward deploy from home ports. The PACOM AOR is so large that movement within the AOR can span great distances and require a significant amount of time. The smaller distance to travel, the less likely a GPS denied environment will affect the ability to navigate; the greater the distance to travel, however, the more likely a GPS denied environment will affect this essential capability. Backup systems can compensate for primary GPS-enabled systems to a degree, but their reduced navigational accuracy will manifest itself over the greater time required for longer voyages.

Deterrence, as a core capability, is significantly affected by GPS unavailability, if an adversary knows details of the disruption or outage. If an outage involved the entire GPS constellation, an adversary would be aware of the exposed vulnerability, as their own GPS-reliant systems would be suffering the same impairments. Additionally, because of its effects on the civilian population, a complete GPS outage would most certainly be broadcast through

global media outlets. Knowing that the United States' primary navigation tool was inoperable gives an adversary insight into a perceived weakness and lessens the powerful military force behind successful deterrence at sea. Although likely not a sole reason for deterrence to fail, it might be seen as an opportunity and potentially the best time for an adversary to strike. Likewise, if the adversary were the direct cause of the GPS outage, they would have almost certainly made provisions so that their own assets could navigate effectively, thus giving their forces an advantage. If the adversary used another space navigation system, like China who has their own satellite navigation system named Beidou, they, too, would be at a distinct advantage.

Sea control, like the other capabilities, involves much more than surface ships alone, but in the narrow scope of this paper, sea control in a GPS denied environment is analyzed with regard to surface ships only. Sea control, the most fundamental naval capability, is the ability to move freely at sea and is a localized and temporary state, with regard to the objective.²⁶ It allows for freedom of movement not only in terms of friendly military action, but also in terms of sea lines of communication and global trade. A friendly force can obtain sea control in one of three ways: 1) by physical destruction of the opponent's navy; 2) by defensive efforts to influence the opponent not to engage in a naval battle; and 3) by implementing a naval blockade.²⁷ Naval ships, in conjunction with aircraft and submarines, are an essential piece of sea control operations in that they provide the means to conduct the PACOM commander's selected method of achieving sea control. A lack of GPS navigation capability onboard U.S. ships could potentially hinder effective sea control operations by negatively affecting the accuracy of ship locations, actual versus desired, as they maneuver in the area of operations. Although ships can operate with a less accurate backup system, all

three methods of obtaining sea control require timely and accurate response of naval assets. Depending on the strength and sophistication of the enemy's force, a lack of GPS navigation onboard U.S. ships could pose substantial difficulties and additional risk for obtaining sea control.

Power projection is the fourth core capability, as put forward in *A Cooperative Strategy for 21st Century Seapower*. Power projection is the ability to project military power ashore and can take various forms, including amphibious warfare, combined operations, raids, invasions, and naval bombardment.²⁸ In most cases, power projection equates to joint operations, which means added complexity in terms of coordination. In addition to coordinating activities with other services, such as the U.S. Marine Corps in an amphibious operation or the U.S. Army in support of an ongoing land operation, naval assets must be in precise locations, at precise times, to ensure operations occur as planned. A naval asset out of place, even by a few nautical miles, can cause unnecessary friction in the operation. Operating in a GPS denied environment, thus, would negatively affect U.S. power projection capability.

Accurate navigation is also necessary for the fifth core capability, maritime security. Maritime security entails countering transnational threats, such as piracy, terrorism, and drug trafficking, in order to protect freedom of the seas for all nations.²⁹ Because these types of threats are smaller in scale than conventional fleets, they require precise navigation to locate smaller vessels on the high seas. A GPS denied environment may prohibit friendly forces from intercepting these transnational maritime threats, although a superior number of friendly assets in the area and dedicated to the mission could potentially compensate for the lack of accurate navigation.

The sixth and final core capability, humanitarian assistance and disaster response, is no different in its dependence on accurate GPS navigation aids. When situations require humanitarian assistance and disaster response, such as PACFLT's response to the 2011 massive earthquake in Japan, time is critical. Naval assets must navigate to affected locations as quickly as possible. Backup navigation methods are not as accurate as GPS, and thus require additional time to navigate to the desired locations. U.S. aid arriving too slowly can cost lives and is not acceptable on a strategic communications level. A humanitarian assistance and disaster response situation can occur in both hostile and non-hostile conditions, and although more likely during a hostile conflict, a GPS denied environment should be considered for each situation.

The six core capabilities described in *A Cooperative Strategy for 21st Century Seapower* provide a solid framework for analysis. A GPS denied environment negatively affects all six capabilities, which potentially degrades the PACOM commander's ability to complete his mission objectives within the AOR. Furthering the analysis, another beneficial way to view the problem is in terms of the center of gravity and critical factors. According to Joint Publication 5-0, a center of gravity is a source of power "from which a system derives its moral or physical strength, freedom of action, and will to act," and it should always link back to the objective.³⁰ Given the PACOM mission of protecting and defending the United States, promoting regional stability, deterring aggression, and responding across the full spectrum of operations should deterrence fail, the operational center of gravity is the physical military force dedicated to the PACOM AOR. Surface ships constitute a large portion of this physical military force, as they sail the seas on a day-to-day basis and are the most visible form of U.S. military capability. Joint Publication 5-0 provides a framework of critical

factors to examine the center of gravity further.³¹ Accurate navigation is a *critical capability* that enables PACOM surface ships to accomplish the mission using the six core capabilities. The *critical requirement* for accurate navigation, then, is GPS, which provides precise navigational signals and includes the associated satellites, ground stations, command and control stations, and user receivers. This critical requirement is also a *critical vulnerability*, meaning that it is vulnerable to attack or exploitation by the enemy. Commanders have a responsibility to protect their own center of gravity, which means they should be aware of any critical vulnerabilities and safeguard them if possible. If a vulnerability is open to exploitation despite efforts to protect it, a commander has an obligation to prepare his forces to operate under such circumstances. In this manner, the PACOM commander must prepare plans to compensate for a GPS disruption or outage and can do so by exploring ways to rebalance the operational factors of time, space, and force.

CONCLUSIONS and RECOMMENDATIONS

There are several ways, with different levels of feasibility, to compensate for a GPS denied environment. First, to counteract the loss of time a GPS denied environment could cause, the commander should consider options to decrease the operating space and increase force. In critical areas, PACOM should forward deploy additional naval assets in the event of a perceived threat to or actual GPS outage. Despite less than optimal navigation, these additional naval assets could support five of the six core capabilities by providing greater force over a smaller area; supporting humanitarian assistance and disaster response missions in this manner is not feasible, as locations in need of support are unpredictable. Decreasing the space by deploying additional force, however, comes at a cost. The additional assets and associated personnel are not immediately available for other emerging priorities, and

increased deployments will have a negative long-term effect on personnel readiness and training, as well as costs for increased maintenance requirements and replacement assets.

Second, the PACOM commander should consider augmenting movement and maneuver with additional assets under his operational control. Military aircraft and submarines, although they themselves may be adversely affected by a GPS outage, could be used as needed to support the core capabilities of forward presence, deterrence, sea control, and power projection. It is more difficult for these platforms to augment maritime security and humanitarian assistance and disaster response because of the nature of the accompanying activities, but depending on the objective and criticality of the task, the PACOM commander should consider diverting assets from their primary tasks to support the maritime environment as needed. Again, this comes at a cost. Assets are limited, and any assets diverted from their primary mission may not be backfilled.

Third, the PACOM surface fleet should train for operations within a GPS denied environment and exercise this capability regularly. Training should include instruction on all onboard alternate navigation systems, including the capabilities and limitations of each as well as specific operating procedures. Celestial navigation should be reviewed as well; this skill is an essential backup that when accomplished correctly can provide accuracy within a three-mile radius. It takes only one to two days to master simple celestial navigation skills, and the cumbersome mathematical calculations that made it time consuming in the past can now be done by computer.³² These skills can prepare the fleet for operations under less than optimal conditions, reducing friction by introducing the concepts and skills needed in the event of a GPS disruption or outage. The PACOM surface fleet currently participates in many recurring exercises, including TALISMAN SABER, KEEN SWORD, and RIM OF

THE PACIFIC,³³ and these represent excellent opportunities to reinforce navigation skills and assess the fleet's readiness to contend with a GPS denied environment. The exercises should be full-scale and realistic, with as little simulation as possible, and conducted over a significant amount of time.

Fourth, the PACOM commander should use the capabilities of U.S. allies to his advantage. GPS is the universally known satellite navigation system, but several other states have built or are in the process of building their own systems, including the European Union, Japan, Russia, and China.³⁴ Depending on the situation, the PACOM commander should leverage relationships to gain access to these capabilities. Current GPS receivers onboard surface ships cannot receive signals from other satellite navigation systems, although plans are in work for the future. A "quick fix" could involve simply obtaining and placing another country's hand-held navigation system receiver, such as GLONASS, Russia's equivalent of GPS, onboard each U.S. surface ship. Although not a perfect fix, as the information from a GLONASS receiver would have to be manually entered in a U.S. surface ship's navigation system, it is one that is feasible with comparable accuracy to GPS. In this manner, the PACOM commander could regain the balance between time, space, and force by restoring accurate navigation capability to near pre-GPS outage levels. A PACOM focus area is to strengthen and advance alliances and partnerships in the region;³⁵ navigation tools and interoperability would be an excellent topic to address.

The above recommendations are immediate and short-term actions to prepare for and respond to a GPS denied environment in the maritime domain. There are other steps to consider in order to obtain a long-term solution to this movement and maneuver problem. First, the PACOM commander should prioritize the development of a long-term technical

solution by placing it on his Integrated Priority List (IPL). Each combatant commander provides an IPL annually, listing his highest priority requirements and providing a recommendation for programming funds in the planning, programming and budget cycle. The IPL is the vehicle where the PACOM commander could publicize the importance of developing a more accurate backup method for GPS, highlight its urgency, and divert funding towards the cause. One potential backup system to GPS, the LORAN-C program, recently lost its funding and was terminated.³⁶ Other systems specific to maritime operations are in work, such as improved inertial navigators and automated celestial navigation, but these efforts could be in jeopardy as a result of current fiscal realities. By placing a long-term solution high on his IPL, the PACOM commander can expect greater attention from the functional component commands on this issue.

Second, in the same manner an enemy may threaten U.S. navigational capabilities, the PACOM commander should seek to hold adversary navigation systems at risk as a deterrent. Depending on the identity of the enemy, this could take different forms. For a conventional threat, this means developing and maintaining the capability to render an enemy's system either temporarily or permanently incapable. For example, the U.S. could develop plans to temporarily disable China's Beidou navigational system by sending false commands to the satellites, or further on the spectrum, permanently disable the system by physically attacking the ground control stations or the satellites themselves. Because of the wide effect this would have not only on an enemy's military capability, but on its civilian population, this decision resides above the PACOM commander. In the event the enemy does not possess its own satellite navigation system, such as smaller countries or non-state actors, holding navigation systems at risk as a deterrent is not effective. PACOM, however, can obtain intelligence to

determine what methods and systems the enemy is using. Local jamming can hinder their navigation capability on a small scale, and although it may not have a deterrent effect, it weakens the enemy's movement and maneuver in the same manner in which a GPS denied environment effects friendly forces, as discussed previously.

SHORT SUMMARY OF POSSIBLE COUNTER-ARGUMENTS

Some may argue that the possibility of a complete GPS outage is so low that no action is needed to mitigate the risk. While it is true that the risk is low, if it occurs, it would add enormous friction to a crisis situation. This friction could be avoided with relatively simple measures, such as training and alternate methods of force management, as described above. These simple measures to prepare for and respond to operations in a GPS denied environment in the maritime domain cost relatively little, with the main effort being the additional thought needed to clearly plan for and implement actions as a response to a potential enemy course of action. Even if the risk is low, the investment to address the problem now could pay exponential dividends in the event of a GPS denied environment. It makes logical sense to address the issue now instead of gambling that future enemies will not exploit this critical vulnerability.

Another counter-argument is that U.S. naval surface ships are equipped with alternate systems that would be "good enough" to navigate in a GPS denied environment. People have been navigating the seas for hundreds of years using only celestial navigation, so why is GPS-level accuracy so important? In civilian operations or during peacetime, perhaps this is a valid argument; the accuracy of celestial navigation up to a three-mile radius on the open ocean might be sufficient. During PACOM contingency operations or crisis situations, however, accurate and timely maritime navigation is needed to present forces in the proper

manner to deter an enemy and, if deterrence fails, fight to win. Accurate navigation at sea, as discussed previously, very clearly affects the way in which PACOM conducts its mission in the maritime domain with respect to the six core capabilities of forward presence, deterrence, sea control, power projection, maritime security, and humanitarian assistance and disaster response. To obtain the most favorable position with respect to an enemy, friendly forces should have the best navigation accuracy possible. If the primary GPS-enabled system is not available, a backup system should provide comparable capability to maintain the military advantage. If one is not available, as is currently the case, the PACOM commander should acknowledge the vulnerability and account for it in planning.

FINAL REMARKS

The PACOM commander should carefully consider the issue of surface ship navigation within a GPS denied environment. As analysis shows, reliance on GPS-enabled navigation systems is a critical vulnerability that can be addressed in the short-term through training and relatively simple, yet carefully thought through, planning and force management. The PACOM commander can also affect long-term solutions through his influence in the budget process and strategic deterrence planning. Implementing these measures will reduce potential friction by protecting against enemy exploitation of a vulnerability and preparing PACOM forces to operate in an unfamiliar environment. Undoubtedly, the PACOM commander is engaged in multiple efforts to place his forces in the most advantageous position possible to accomplish the PACOM mission and objectives, and he has many competing priorities. Preparing to operate in a GPS denied environment, however, is one effort he should not neglect.

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